Absolute Calibration of Field Reflectance Radiometers

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ABSTRACT: A method is described whereby field reflectance radiometers can be calibrated in an absolute sense using equipment available at most agricultural or environmental research locations. A radiometer is positioned directly above a calibrated standard reflectance panel that is horizontal to the Earth's surface. The sun's direct beam is separated from the total by measuring the total, shading the panel with a nontransparent shield held between the sun and the panel, measuring the diffuse component, and subtracting the diffuse from the total. These measurements are repeated periodically from shortly after sunrise to near solar noon. A graph of the logarithm of the radiometer response to the direct beam versus the secant of the solar zenith angle (known as a Langley plot) yields the spectral-extinction optical thickness of the atmosphere as the slope and the logarithm of the exoatmospheric irradiance divided by the calibration factor as the intercept. Calibration factors for two radiometers were within 10 percent of those obtained by other methods, indicating that this technique is a viable method for the absolute calibration of field radiometers.

INTRODUCTION

SMALL, LIGHTWEIGHT, RADIOMETERS that measure radiation in the reflected solar portion of the electromagnetic spectrum are currently being used to obtain spectral data for environmental and agricultural research projects. For the most part, these radiometers are used in conjunction with a reference reflectance panel made from flat metal plates coated with highly reflecting substances such as $BaSO_4$ (Robinson and Biehl, 1979) or Halon (Schutt *et al.*, 1981). With a calibrated reflectance panel, the reflectance factors of targets can be calculated by dividing the target radiance by the panel radiance, if the radiances from both surfaces are measured at nearly the same time. For some purposes, however, it is necessary to quantitatively measure the radiance reflected from targets. For example, the calculation of the net amount of radiation absorbed by a plant canopy can be made if the irradiance at, and the reflected radiance from, the canopy are known (Jackson *et al.*, 1985). To accomplish this using reflectance radiometers, calibration factors for each channel of the radiometer must be known.

Calibration factors for some radiometers are available from their manufacturer, whereas other radiometers are delivered uncalibrated. Calibration procedures are best carried out in well equipped optical laboratories. Such facilities are not ubiquitous, and are essentially unavailable to a number of researchers who routinely use small field radiometers. In the absence of a precise laboratory calibration, a field calibration procedure would be of benefit. This report describes a field procedure for the calibration of reflectance radiometers using equipment already available at most environmental research stations.

METHOD

The proposed method is an adaptation of a technique for determining the solar constant from ground based measurements (Shaw *et al.*, 1973; Slater, 1980). For any solar zenith angle (θ_z), the spectral irradiance on a surface perpendicular to the direct solar incident flux is,

$$E_\lambda = E_{\lambda o} e^{-\tau(\lambda)\sec\theta_z} \qquad (1)$$

where $E_{\lambda o}$ is the exoatmospheric irradiance (the spectral irradiance outside the Earth's atmosphere on a plane one astronomical unit from the sun and perpendicular to the incidence flux), and $\tau(\lambda)$ is the spectral-extinction optical thickness at the wavelength λ.

Observations of E_λ are made with a radiometer for several zenith angles from just after sunrise to near solar noon on a single day. It is assumed that $\tau(\lambda)$ remains constant during the measurement period, and that the radiometer output signal is linear with respect to input radiant energy. The graph of $\ln(E_\lambda)$ versus $\sec(\theta_z)$, known as a Langley plot, will be linear if the assumptions are sufficiently met. The slope of the line is the spectral-extinction optical thickness, and the intercept is the natural logarithm of the exoatmospheric irradiance. The solar zenith

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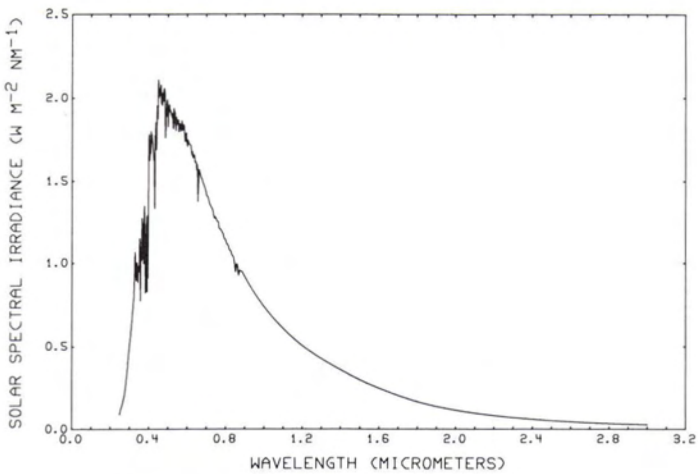

FIG. 1. Solar spectral irradiance at the top of the atmosphere.

angle can be directly measured, but it is readily calculated from a time measurement and the ephemeris of the sun (List, 1958, Table 169).

The irradiance (E_λ) can be measured by pointing a radiometer, having a field of view that just includes the solar disk, directly at the sun. The irradiance is the produce of an output voltage (V) times a calibration factor (c).

For an uncalibrated radiometer, Equation 1 becomes

$$Vc = E_{\lambda o} e^{-\tau(\lambda) \sec \theta_z} \quad (2)$$

If $\ln(V)$ is plotted versus $\sec\theta_z$, the slope is $-\tau(\lambda)$ and the intercept is $\ln(E_{\lambda o}/c)$. If $E_{\lambda o}$ is known, the calibration factor (c) is

$$c = E_{\lambda o}/e^{A} \quad (3)$$

where A is the intercept of the Langley plot.

Equation 2 requires that V be in response to the direct solar incident flux. A radiometer having a field of view (FOV) of 3° pointed directly at the sun would see less than 2 percent diffuse radiation (Shaw *et al.*, 1973). With field radiometers such as the Exotech Model 100-A* and the Barnes 12-1000 Modular Multispectral Radiometer (MMR)*, the available FOV's are 1° and 15°. Using a 1° FOV, alignment of the radiometer optics with the solar beam would require precision solar tracking equipment. Using a 15° FOV would allow a significant portion of diffuse radiation to reach the detector.

An alternate procedure is to measure the direct radiant flux reflected from a horizontal panel of known reflectance. This removes the stringent field of view requirement and allows radiometers having any field of view less than, say, 20° to be calibrated. Fields of view larger than about 20° would require either an excessively large standard reflectance panel or placement of the radiometer close to the panel. The latter condition could cause errors by the instrument blocking a significant amount of diffuse radiation and/or re-reflecting radiation from the panel.

The procedure depends upon the assumption that the standard reflectance panel is a perfect lambertian reflector. This requirement can be approximated if the reflectance of the panel is accurately known at all illumination angles that may be encountered during field measurements.

The evaluation of $E_{\lambda o}$, the corrections necessary for the reflectance panel to approximate a perfect lambertian reflector, and experimental procedures are discussed in the following sections.

EXOATMOSPHERIC IRRADIANCE

Data for solar spectral irradiance at the top of the atmosphere were obtained for the wavelength interval from 0.33 to 1.25 μm from Neckel and Labs (1981), for 1.25 to 2.95 μm from Pierce and Allen (1977), and for wavelengths below 0.33 μm from Slater (1980). The data were interpolated to yield values for each nanometre between 0.25 and 3.0 μm (Figure 1).

Response functions for the four Exotech bands and the seven reflectance bands of the Barnes 12-1000 MMR are shown in Figure 2. Response function data are usually found in the radiometer instruction manual. The Exotech simulates the four Landsat multispectral scanner system (MSS) bands and the

* Trade names and company names are included for the benefit of the reader and imply no endorsement of the product or company by the U. S. Department of Agriculture or the University of Arizona.

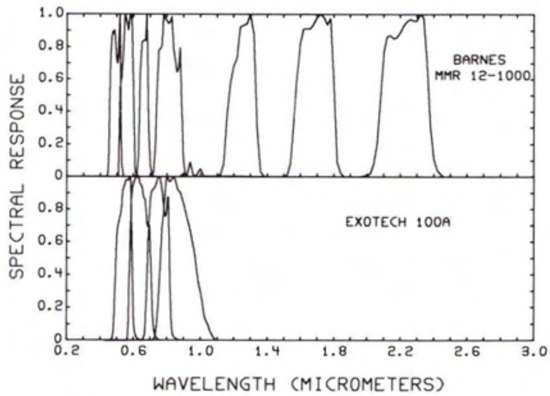

FIG. 2. Spectral response functions for two field radiometers.

MMR simulates the six solar reflective Landsat Thematic Mapper (TM) bands. The MMR also has a band at 1.15 to 1.30 μm. Nominal wavelength intervals for the two instruments are given in Table 1.

The exoatmospheric irradiance within the wavelength interval (the symbol $E_{\lambda o}$ will now apply to the WLI) for each band of the two instruments was obtained by summing the product of the irradiance (Figure 1) and the response functions (Figure 2) for each radiometer band of interest. The results are presented in Table 1. The data are for the mean Earth-sun distance. $E_{\lambda o}$ varies with the square of the Earth-sun distance, differing by about 7 percent between January and July. The values for $E_{\lambda o}$ given in Table 1 can be corrected to the actual Earth-sun distance by dividing them by the square of the radius vector of the Earth (r) for each measurement day. Tabular values of the radius vector are available (List, 1958, Table 169), but they can be approximated using the relation (Gurney and Hall, 1983)

$$r = 1 + 0.0167\sin[2\pi(D - 93.5)/365] \quad (4)$$

where D is the day of year. With this correction, and dividing by π to put the calibration factor in terms of radiance per volt, Equation 3 becomes

$$c = E_{\lambda o}/(r^2 e^\wedge \pi) \quad (5)$$

with c having units of W m^{-2} sr^{-1} V^{-1}.

When ephemeris tables are used to calculate the solar zenith angle, the solar time must be noted at the precise time that the measurements are made. An uncertainty in the time measurement of about 10 s would cause an error of about 0.1 percent in the zenith angle calculation for angles less than 75° (Thomason *et al.*, 1982).

REFLECTANCE PANEL

Reflectance factor data for a panel painted with $BaSO_4$ was provided by LARS, Purdue University (L. L. Biehl, personal communication). Reflectance factor data for 10 and 20° incidence angles were interpolated to yield data at 15° for each band of the Exotech and the MMR (Table 1). Panel reflectance factors were measured as a function of incidence angle from 15 to 75° using a device that allowed the panel to be held at a known angle to the sun's rays. With the MMR radiometer positioned about 1 m above and perpendicular to the panel, a measurement of the direct solar radiation was made (using a shading technique described in the following section). Subsequently, the incidence angle was changed and

TABLE 1. NOMINAL WAVELENGTH INTERVALS (WLI), EXOATMOSPHERIC IRRADIANCE WITHIN THE SPECIFIED WLI OF THE EXOTECH MODEL 100-A AND THE BARNES 12-1000 MMR RADIOMETERS, AND $BaSO_4$ PANEL REFLECTANCE FACTORS AT θ_z = 15° FOR EACH WLI.

Radiometer	Band	Nominal wavelength (μm)	Exoatmospheric irradiance (W m^{-2})	Panel reflectance factor
Exotech				
	1	0.5 – 0.6	167.6	0.942
	2	0.6 – 0.7	188.2	0.936
	3	0.7 – 0.8	157.3	0.929
	4	0.8 – 1.1	197.5	0.914
Barnes MMR				
	1	0.45 – 0.52	112.4	0.948
	2	0.52 – 0.60	134.4	0.941
	3	0.63 – 0.69	72.2	0.935
	4	0.76 – 0.90	145.0	0.922
	5	1.15 – 1.30	69.1	0.897
	6	1.55 – 1.75	49.9	0.855
	7	2.05 – 2.30	22.0	0.757
	8	10.5 – 12.5	--	--

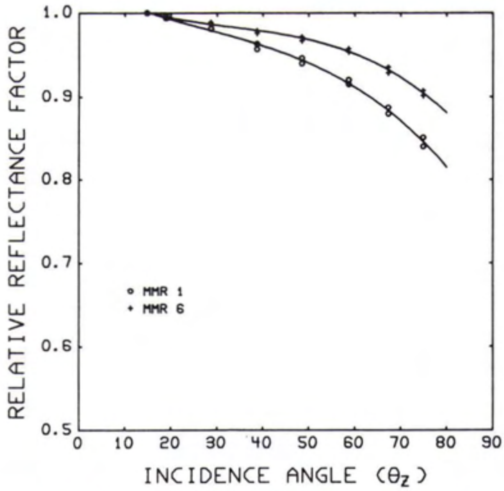

FIG. 3. Relative reflectance factors of a $BaSO_4$ panel as a function of incidence angle for two bands of a field radiometer.

the measurement repeated. Relative reflectance factors were calculated as the ratio of radiometer output voltage to the voltage at 15°. The choice of 15° as the the reference angle was dictated by the fact that, for smaller incidence angles, the radiometer shadowed the panel. A measurement sequence for eight incidence angles required about 15 minutes.

Values of relative reflectance factors for the $BaSO_4$ panel as measured by MMR radiometer bands 1 and 6 are shown in Figure 3. Data for MMR bands 2 to 5 are intermediate to those shown, and those for MMR-7 are slightly higher than for MMR-6. Third degree polynomial equations were statistically fit to the data for each MMR band. The lines in Figure 3 indicate how well the data from two measurements were represented by the equations. Equations for MMR bands 2, 3, and 4 were used as representative for similar bands of the Exotech.

The reflectance factor of the panel at any zenith angle $R(\theta_z)$ is the product of the reflectance factor at 15° and the relative reflectance factor. In practice, the polynomial approximations of the relative reflectance factor data (Figure 3) were used in the calculations.

Because the panel was kept horizontal during the measurements, instead of perpendicular to the solar beam as required by Equation 1, the voltage that would result if the standard reflectance panel were a perfect lambertian reflector held perpendicular to the sun's rays is approximated by

$$V = V_h/[R(\theta_z)\cos\theta_z] \qquad (6)$$

which is the value of V to be used in the Langley plots. The term V_h is the radiometer voltage when viewing a horizontal panel.

If radiometer gain settings are other than 1 during measurements, the voltage should be adjusted to represent a gain of 1. The output from the PbS detectors (Bands 5 to 7) of the MMR are ambient temperature sensitive. A procedure to adjust the output to a reference temperature was described by Jackson and Robinson (1985). The Langley plot for bands 5 to 7 of the MMR will not be linear if the temperature effect is not compensated for.

Measurement of Direct Solar Radiation

The direct component of the irradiance can be separated from the total by measuring the total, shading the panel with a nontransparent shield held between the sun and the panel, and measuring the diffuse component, with the direct component being the difference between the total and the diffuse. The use of a shading device (which should be held at as great a distance from the panel as practical) blocks a portion of the sky, reducing the amount of diffuse radiation that strikes the panel by a small amount. The error caused by the use of the shade and the error caused by the time difference between measurements of the total and the diffuse can be minimized by holding the shield so that the shaded area is to the side of the panel while the total irradiance is measured, then moved sideways to shade the panel for the diffuse measurements, then moved back to the original position for another total irradiance measurement. The before and after total irradiance measurements are averaged to yield a value corresponding to nearly the same time as that when the diffuse measurements were made. By holding the shield the same distance from the panel during all measurements, the portion of the sky blocked by the object is similar, thus reducing the error caused by its use. For a detailed discussion of this type of measurement see Che *et al.* (1985).

Measurement Procedure

An Exotech and a Barnes MMR (serial no. 119) were mounted side-by-side at the end of a rotatable boom which held the instruments about 1.7-m above a 1.2 by 1.2-m $BaSO_4$ painted horizontal panel. Outputs from the two radiometers were recorded using a portable data acquisition and storage device that also noted the time of measurement. Measurements were made on six dates, 19 November 1983, 15 December 1983, 13 April 1984, and 8, 10, and 20 June, 1984, beginning shortly after sunrise and continuing periodically until about an hour before solar noon. A 1.3 by 1.3-m flat shield mounted at the end of a 3.5-m pole was used to shade the panel during measurements of diffuse radiation. The measurement sequence was total (sunlit panel), diffuse (shaded panel), and total.

When the measurements were completed, the data were downloaded to a computer. The voltage data

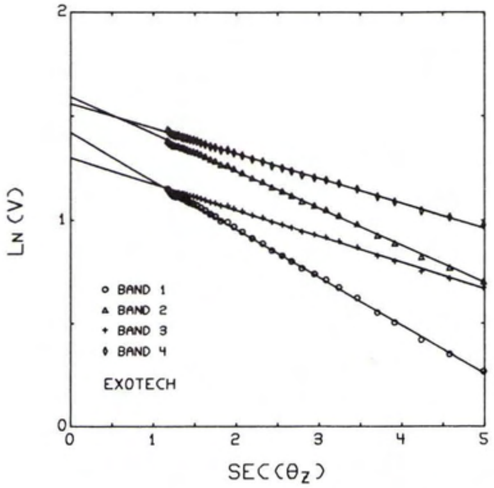

FIG. 4. Langley plots for the four Exotech bands. Data were taken on 13 April 1984.

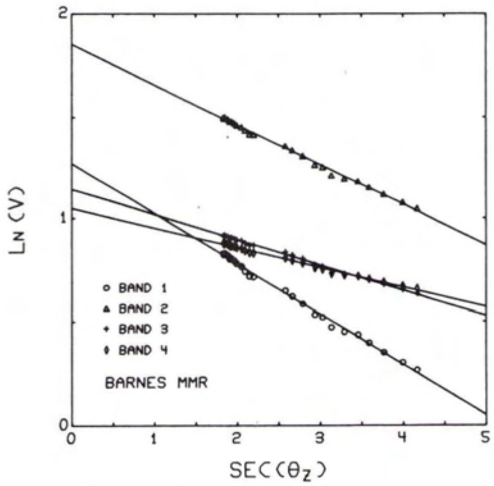

FIG. 5. Langley plots for MMR bands 1 to 4. Data were taken on 15 December 1983.

were, when necessary, adjusted to a gain of 1 and the ambient temperature sensitive channels adjusted to a reference temperature of 25°C (Jackson and Robinson, 1985). For each channel on each radiometer at each measurement time, the two total (sunlit) data were averaged and the diffuse subtracted to yield a voltage value (V_h) due to direct radiation at the time of the diffuse measurement (the time at which θ_z was calculated). Using θ_z, the relative reflectance factor was calculated using the appropriate polynomial equations (see discussion of Figure 3), the panel reflectance factors at 15° were taken from Table 1, and the voltage V_h was adjusted to V using Equation 6. Plots of $\ln(V)$ versus $\sec(\theta_z)$ were made

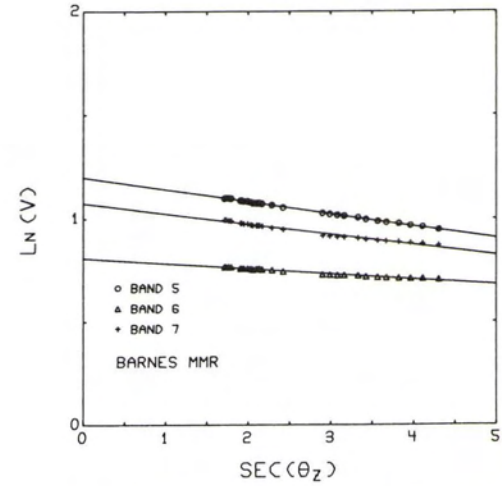

FIG. 6. Langley plots for MMR bands 5 to 7. Data were taken on 19 November 1983.

to obtain the intercept A which, when used in Equation 5, yielded the calibration factors.

RESULTS AND DISCUSSION

Representative Langley plots for eleven bands and for three measurement dates are shown in Figures 4 to 6. In all cases the data are linear, a necessary but not sufficient condition for the underlying assumptions to be met. Reagan *et al.* (1984) showed by model simulations that a linear relation can result when the spectral-extinction optical thickness varies temporally. This emphasizes the necessity of making measurements under clear, stable weather conditions.

If the temperature correction had not been made to the PbS detector outputs for MMR bands 5 to 7, the data would have been markedly non-linear, being concave downward.

The calibration factors for the two instruments are given in Tables 2 and 3. Table 2 includes the calibration factors for the Exotech as furnished by the manufacturer. The percent difference between the company measured and the Langley plot results range from −4.0 percent for band 2 to 9.6 percent for band 3. There were no data available with which the MMR calibration factors (Table 3) could be directly compared.

A secondary comparison was made with a second MMR (S# 116) at White Sands, New Mexico on 28 October 1984. Langley plots of the data provided a calibration factor for the first four MMR bands. These data, along with the means for bands 1 to 4 of MMR S# 119 from Table 3, are presented in Table 4. Also included are calibrations for bands 1 and 3 for MMR S# 116 from a laboratory-based procedure (Phillips, 1985). The detector temperature was not monitored

TABLE 2. CALIBRATION FACTORS FOR THE EXOTECH MODEL 100-A DETERMINED FROM LANGLEY PLOTS AND RESPONSE FUNCTIONS GIVEN IN THE MANUFACTURERS INSTRUCTION MANUAL. ALL CALIBRATION FACTORS HAVE UNITS OF $W\,m^{-2}\,sr^{-1}\,V^{-1}$.

Date of measurement	Band 1	Band 2	Band 3	Band 4
19 Nov 83	12.5	11.8	13.6	13.5
15 Dec 83	12.1	11.5	13.3	13.4
13 Apr 84	12.8	12.1	13.6	13.1
08 Jun 84	12.0	11.6	13.3	13.2
10 Jun 84	13.2	12.5	14.1	13.9
20 Jun 84	13.6	12.7	14.2	13.7
Mean (SD)	12.7 (0.6)	12.0 (0.5)	13.7 (0.4)	13.5 (0.3)
Company calibration	12.7	12.5	12.5	12.9
Percent difference	0	−4.0	9.6	4.7

TABLE 3. CALIBRATION FACTORS FOR THE BARNES MMR 12-1000 S#119 DETERMINED FROM LANGLEY PLOTS AND RESPONSE FUNCTIONS GIVEN IN THE MANUFACTURERS INSTRUCTION MANUAL. ALL CALIBRATION FACTORS HAVE UNITS OF $W\,m^{-2}\,sr^{-1}\,V^{-1}$.

Date of measurement	Band 1	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7
19 Nov 83	10.8	7.16	7.77	17.0	6.78	7.26	2.45
15 Dec 83	10.4	6.91	7.58	16.7	6.72	7.00	2.41
13 Apr 84	11.2	7.04	8.09	17.0	6.59	6.94	2.40
08 Jun 84	10.4	6.62	7.83	16.7	6.91	7.10	2.41
10 Jun 84	11.4	7.13	8.37	17.4	7.26	7.39	2.48
20 Jun 84	11.5	7.16	8.34	17.2	7.00	7.23	2.44
Mean	11.0	7.00	8.00	17.0	6.88	7.15	2.43
SD	0.5	0.21	0.32	0.3	0.24	0.17	0.03

TABLE 4. COMPARISON OF CALIBRATION FACTORS FOR 4 BANDS OF TWO MMR RADIOMETERS AND FIELD AND LABORATORY CALIBRATIONS FOR 1 BANDS OF ONE RADIOMETER. THE FACTORS HAVE UNITS OF $W/m^{-2}\,sr^{-1}\,V^{-1}$.

Date of measurement	Band 1	Band 2	Band 3	Band 4
SN#119	11.0	7.00	8.00	17.0
SN#116 (field)	9.8	13.5*	7.72	17.0
SN#116 (lab)	10.3	--	7.57	--

*The internal gain adjust was changed from the factory setting.

for S# 116, precluding the calculation of calibration factors for bands 5 to 7. On this radiometer, the gain on band 2 had been internally adjusted from the factory setting, invalidating any comparison of that band. For the following comparison we make the assumption that, because S# 116 and S# 119 were made at the same time, their calibration factors are similar (for bands 1, 3, and 4).

The calibration factors for these two instruments differed by 12 percent in band 1, by 3.6 percent in band 3, and were identical for band 4. The factors for both instruments are reasonably close to the laboratory-based calibration of bands 1 and 3. These data support the premise that the Langley plot method is a viable means of obtaining calibration factors using field data.

The spectral-extinction optical thickness (τ), being the slope of the Langley plots, is readily obtained from the same data as the calibration factors. This parameter is a measure of the extent to which the atmosphere scatters and absorbs the irradiance within the spectral bands of the MMR. Values of τ for each of the eleven bands are given in Table 5. Differences between the six measurement dates are evident, with 8 June 1984 having the highest values. Two days later the next to lowest values for the six days were recorded. Although both days were cloud-free, 10 June apparently had less atmospheric contaminants than did 8 June. Che *et al.* (1985) presented a detailed discussion of the measurement of τ using a field radiometer and a calibrated reflectance panel.

The data and the standard deviations of the cal-

TABLE 5. VALUES OF THE SPECTRAL-EXTINCTION OPTICAL THICKNESS (τ) OBTAINED FROM SLOPES OF LANGLEY PLOTS FOR SEVEN BANDS OF THE BARNES MMR S#119 AND THE FOUR EXOTECH BANDS.

Date of measurement	Band						
	1	2	3	4	5	6	7
Barnes MMR							
19 Nov 83	0.211	0.169	0.105	0.074	0.059	0.025	0.050
15 Dec 83	0.243	0.197	0.122	0.095	0.086	0.049	0.087
13 Apr 84	0.286	0.239	0.157	0.122	0.094	0.054	0.072
08 Jun 84	0.353	0.292	0.195	0.149	0.116	0.067	0.095
10 Jun 84	0.225	0.185	0.112	0.089	0.074	0.031	0.063
20 Jun 84	0.233	0.190	0.117	0.089	0.079	0.039	0.068
Exotech							
19 Nov 83	0.165	0.123	0.078	0.072			
15 Dec 83	0.187	0.140	0.096	0.095			
13 Apr 84	0.232	0.179	0.127	0.120			
08 Jun 84	0.298	0.229	0.164	0.153			
10 Jun 84	0.181	0.133	0.092	0.089			
20 Jun 84	0.183	0.136	0.093	0.090			

ibration factors given in Tables 2 and 3 indicate that the method is reasonably precise. The variation between the six measurements does not appear to be related to time nor to the degree of atmospheric scattering (Table 5).

The accuracy of the measurement depends upon the accuracy of the exoatmospheric irradiance data and the reflectance data for the standard panel. Errors in $E_{\lambda o}$ will cause a proportional error in c. The most probable error in exoatmospheric irradiance within the wavelength interval as given in Table 1 would be in the response functions used in the calculation of the values. These functions could be determined for a particular instrument using equipment available in most optics laboratories.

If the reflectances of the standard panel are in error by a multiplicative amount, the calibration factors will be in error by the negative of that amount. Thus, if the relative reflectance of the panel is known with sufficient accuracy, but the reference reflectance at 15° is in error, the calibration factors can be easily corrected when the true reflectance values are known. If the relative reflectances are in error, the Langley plots may not be linear.

Equations 1 and 2 are expressions of Beer's law which was derived for monochromatic radiation. Thomason *et al.* (1982) showed that less than 0.1 percent error would result from using a 0.01-μm wavelength interval. The wavelength intervals used ranged from 0.06 to 1.1 μm. However, a twenty-fold larger error (2 percent) can be tolerated in the field method discussed here.

CONCLUDING REMARKS

The Langley plot technique is a viable field method for absolute radiometric calibration at the 10 percent level. Requirements are that the reflectance of a standard panel be known as a function of incidence angle, and that the exoatmospheric irradiance be known for the wavelength interval of each channel of the radiometer. The method is rather simple to implement but requires several hours to obtain one set of calibration factors.

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Forum

Comments on Evaluations of Simulated SPOT Data

The August 1985 issue of *Photogrammetric Engineering and Remote Sensing* contained a number of articles evaluating products from the 1983 SPOT Simulation Campaign. Because conclusions from the simulation pertain also to the utility of the satellite data, it is appropriate to clarify differences between the simulation and satellite data which may affect some applications.

The paper by Ackleson and Klemas discusses the utility of the simulation data for discriminating water masses, emphasizing the low noise content of the simulation data. However, the simulation data have lower noise content than is to be expected from the satellite data; e.g., Saint and Weill (1984) present noise values for the three 20-m channels (S1, S2, and S3) and the panchromatic channel (P).

Radiometric Noise	S1	S2	S3	P
SPOT (Nominal) NeΔL	0.14	0.15	0.11	0.15
Simulation NeΔL	0.05	0.05	0.03	0.05

Radiometric noise is given in mW $cm^{-2}sr^{-1}\mu m^{-1}$)

"The simulations are in this respect significantly better than real data, but this can be taken into account by using the calibration coefficients on the CCTs to compute the noise equivalent digital count corresponding to the noise and quantization levels of SPOT." This computation requires knowledge of the satellite calibration coefficients, as described by Price (1984). However, in the author's experience with two scenes, the calibration coefficients are not correct in the simulation data sets. Thus, the conversion to satellite equivalent data is problematic. The difference between simulation and satellite data is expected to be most significant in cases similar to that studied by Ackleson and Klemas having low surface reflectivities.

In addition, Ackleson and Klemas state that "It is anticipated that banding will not be a problem within the operational SPOT data because of the linear array configuration of the sensor." However, the simulation data again present an optimistic picture, as the simulation data were obtained by a Daedalus scanner with a single detector per channel, with scanning by means of a rotating mirror, while the SPOT satellite sensor will have some thousands of detectors. It is likely that minor residual banding will remain after calibration, unless special techniques are used (Bernstein *et al.*, 1985). For data which have not been geometrically corrected, this effect will be present as vertical striping associated with the pushbroom scan of the sensor along the satellite track.

Several authors, e.g., DeGloria, have carried out photointerpretation of the imagery produced in conjunction with the SPOT Simulation Campaign. Several caveats apply to the availability of such satellite products:

- Although the simulation imagery included 10-metre multispectral image products produced from the high resolution aircraft data, the 10- and 20-metre satellite data will not be coregistered by the satellite instruments. This task must fall to the user or to the SPOT Corporation, at least until the launch of SPOT 3 and 4, which will acquire 10- and 20-m data in registered form. In contrast, the planned Landsats 6 and 7 will be able to acquire 15-m panchromatic data coregistered with the multispectral 30-m data.

(continued on page 211)